CP violation, single lepton polarization asymmetry, and polarized *CP* asymmetry in $B \to K^* \ell^+ \ell^-$ decay in the four-generation standard model

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In this paper we present a study of *CP* asymmetry, single lepton polarization asymmetry and polarized *CP* asymmetry in $B \to K^* \ell^+ \ell^-$ decay within the four-generation standard model. Taking $|V_{t's}^* V_{t'b}| = 0.01, 0.02, 0.03$ with phase $\{60°–120°\}$, which is consistent with the $b \to s\ell^+\ell^-$ rate and the Bs mixing parameter Δm_{Bs}, we find that *CP* asymmetry, single lepton polarization asymmetry and polarized *CP* asymmetry are sensitive to the existence of the fourth generation. This can serve as an indirect method to search for new physics effects, in particular, to search for the fourth-generation quarks(t', b') via their indirect manifestations in loop diagrams.

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I. INTRODUCTION

The simple replication of chiral matter is a straightforward extension of the standard model. This fourth generation is often considered and ruled out or disfavored by many researchers. This extension has recently gained more attention (for the most recent studies see [1]) after measurement of direct *CP*-asymmetry of $B \to K\pi$ decays [2] and the nonvanished *CP* phase measured in $b \to s$ transition by CDF [3] and D0 [4]. These issues, in particular, the nonvanished *CP* phase measured in $b \to s$ transition cannot be explained by 3×3 the Cabibbo-Kobayashi-Maskawa (CKM) matrix. A consequential extension of the three-generation standard model (SM3) to the four-generation standard model (SM4) has better solutions to some of the theoretical and experimental problems. Such extension can include extra weak phases in the quark mixing matrix. This might introduce a better solution to the problem related to baryogensis [5]. SM4 can also explain the direct *CP*-asymmetry of $B \to K\pi$ decays [6]. The reasons for discarding the fourth family are based on the interpretation of electroweak precision data and LEP II experiments. Kribs *et al.* indicated that the electroweak precision tests are not in conflict with the existence of the fourth family if the quark mass of the fourth generation satisfy the following relation [7]:

$$m_{t'} - m_{b'} \approx \left(1 + \frac{1}{5}\ln\frac{m_H}{115}\right) \times 55. \tag{1}$$

One of the consequences of their study is extension of the bounds on the Higgs mass [7]. Furthermore, a 4×4 CKM matrix includes more weak phases than the 3×3 CKM which leads to sizable increases in the calculation of *CP* asymmetry [8,9]. The 4×4 CKM matrix clearly affects flavor physics [10–14]. Considering many aspects of the fourth family, some of which are discussed above, the search for the fourth family must be included in the LHC.

In this study, we enlarge the standard model with a complete sequential fourth family of the chiral quark. The fourth quark can contribute in the flavor-changing neutral processes (which are loop induced in the SM) like the other three generations. Thus, the mass and mixing parameters of 4×4 CKM can change the rate of the physical observables, with respect to the three-generation standard model (SM3) calculations. $b \to s\ell^+\ell^-$ is a loop-induced transition in the SM. Like u, c, t quarks, the fourth family t' quark can contribute in this transition. $B \to K^*\ell^+\ell^-$ decay in the quark level is described by $b \to s\ell^+\ell^-$ transition. $B \to K^*\ell^+\ell^-$ decay has been widely studied within SM and beyond [15–23]. The various observables of this decay are going to be measured at the LHCb. Here, we study the *CP* asymmetry, single lepton polarization asymmetry and polarized *CP* asymmetry in $B \to K^*\ell^+\ell^-$ decay in the SM4. Note that single and double lepton polarization asymmetries have been studied in the SM3 and in the model independent approach by Refs. [24,25].

The outline of the paper is as follows: In Sec. II, we calculate the decay amplitude and single lepton polarization *CP* asymmetry of the $B \to K^*\ell^+\ell^-$ decay within SM4. In Sec. III we present the calculation of unpolarized and polarized *CP* asymmetry. Section IV is devoted to the numerical analysis and discussion of the considered transition as well as our conclusions.

II. STRATEGY

In this section, we present the theoretical expressions for the decay widths within SM4. As we mention above, t' can contribute to the $b \to s$ transition as u, c and t quarks do.

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